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EXPERIMENTAL INVESTIGATION OF STRESS CONCENTRATION FACTOR IN A UNIDIRECTIONAL CARBON/E-GLASS FIBER HYBRID COMPOSITE

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ABSTRACT

In this study, an analysis of fiber reinforced and symmetrically laminated hybrid composite plates containing a circular hole is carried out by the uniaxial tensile test using extensometer method. The lamina used in various specimens is carbon/epoxy and E-glass/epoxy with orientation of 0^0, 45^0 and 90^0. Initially, the stress state of a specimen of specified orientation without hole is studied followed by the stress concentration around a circular hole of the same specimen. When the fibers are loaded unidirectional and composite lie at an angle to the stress axis, the effective strength of the composite is reduced. A composite plate with central hole has found wide spread applications in various fields of engineering such as aerospace, marine, automobile and mechanical. It is helpful to investigate the crack propagation and failure of the composites which would help in damage analysis and damage resistance.

KEYWORDS: Hybrid Composite, Stress Concentration, Unidirectional, Crack Propagation, Damage Analysis

INTRODUCTION

Fiber reinforced composites are one of the oldest and most widely used composite materials in industries. Fiber reinforced polymer composites are experiencing increasing usage in the engineering industries as they offer combination of properties which are better than provided by traditional metallic materials. Aerospace, automobile, marine and other industries as they possess high specific modulus, high specific strength, high stiffness, low density and long fatigue life. In order to enhance the properties of the existing composites, hybrid composites are being developed. Hybrid composite is the mixture of different composite layers i.e. Carbon/Epoxy and E-glass/Epoxy.Carbon/Epoxy is efficient in storing the greater amount of energy, has high strength, stiffness and low weight. On thecontrary, it has low impact strength and in the case of contact with a metal, galvanic corrosion would cause some problems.Very high cost is another drawback for practical use. Compared to carbon fibers, glass fibers have lower strength andstiffness, higher density, better corrosion resistance, higher impact strength and lower cost.

A good combination of thematerial properties and cost is obtained with the glass fibers. Hence, combination of both the composites into layers willprovide desirable material properties and also cost effective as composites usage in developing commercial products have increased, the study of the detailed design aspects for structural components are also on rise. Extensive and accurate knowledge of stresses, deflections and stress concentration factors are needed for design of laminated composite plates with central circular hole which have widespread applications. The study of composite laminates with stress concentrations is of great importance in design because of the resulting strength reduction and life reduction due to damage growth around these stress concentrations. Stress concentration arises from any abrupt change in

geometry of plate under loading. As a result stress distribution is not uniform throughout the cross-section. Areas having stress concentration are prone to failures such as fatigue and plastic deformation.

Rao et al. [1] determined the stress in rectangular and square cut-outs in symmetric laminates and conclusion drawn is that the maximum stress and its location mainly depend on the type of loading. Jain and Mittal [2] studied the effects of fiber orientation on stress concentration factor in composite plate with central circular hole under transverse static loading by applying two dimensional finite element methods. Lotfi Toubal et al. [3] carried out the stress concentration characterization study of a laminate carbon/epoxy by using 3D speckle interferometry to measure the deformation and contour of the measuring field with sub micrometer accuracy. N. Troyani et al. [4] determined the in-plane theoretical stress concentration factors for rectangular plates with central circular holes under uniform tension using finite element method. Moon Banerjee, et.al [5] studied the influence of stress concentration and deflection due to singularity for isotropic and orthotropic composite materials in various parametric conditions. Results showed significant role of thickness -to- width of plate (T/A) and diameter-to-width (D/A) ratio on stress concentration factor (SCF).

M. Yasar Kaltakci, et.al [6] analyzed the stress state of fiber reinforced, symmetrically laminated composite plates containing circular holes. Results show that as the fiber orientation angle changes, maximum stress value around the Hole and angular location of that stress value changes. Y. Swolfs et al. [7] investigated the stress redistribution after a single carbon fiber breakage in unidirectional glass/carbon hybrid composites using three dimensional finite element models. K.G. Satish et al. [8] investigated the experimental study of the effect of hybrid composite specimen subjected to in-plane tensile and compressive loading and established the relationship between the tensile/compressive strength, fiber content and orientation. Shahzad Alam et al. [9] concluded that glass fiber orientation has no effect on hardness of GRP composites but has small effects on density and impact strength of composite materials and widely affects tensile strength of composites.

The aim of this paper is to evaluate the stress concentration factor (SCF) and the effects of fiber orientation on the stress concentration factor for the unidirectional hybrid composite plate composed of E-glass/carbon fibers system with central circular hole under uniaxial loading.

EXPERIMENTAL PROCEDURE

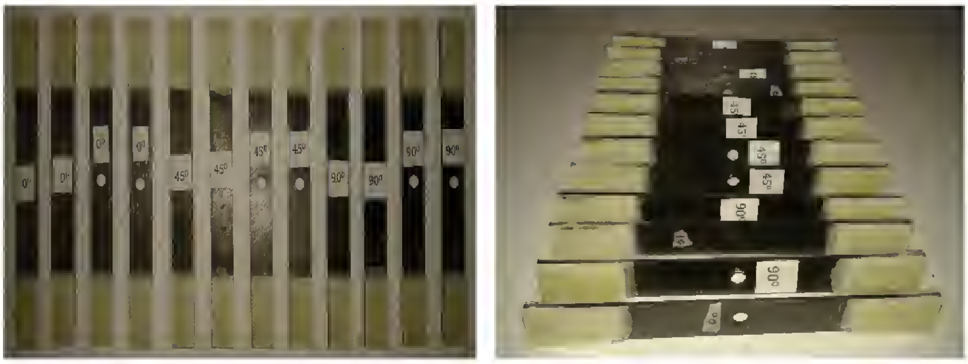
Materials

Investigation was carried on a hybrid composite of unidirectional E-glass and Carbon fiber in epoxy resin. The density of the E-glass fibers was approximately 225gsm (Grams per sq. meter) and that of carbon fiber was approximately 275gsm. The matrix consisted of resin LY556 and hardener HY951. LY556 resin is a bifunctional epoxy resin i.e. diglycidyl ether of bisphenol-A (DGEBA) and HY951 is an aliphatic primary amine, viz., triethylene tetramine – TETA.

Specimen Preparation

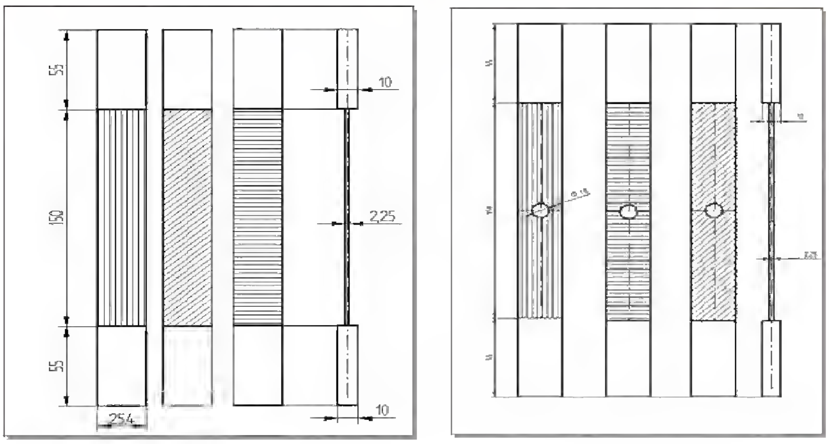
The laminate of dimensions 400mmx500mm was prepared. The laminate consisted of totally eleven layers of fabric, of which six were of E-glass and five were of carbon fiber. The final thickness of the laminate was 2.5mm after fabrication. The weight ratio of the fabric and the matrix was maintained at 65% and 35% by weight respectively. The matrix consisted of resin LY556 and hardener HY951. The weight ratio of resin to hardener was maintained at 10:1. The bottom most fabric, i.e. E-glass fabric was placed on the cleaned surface. A layer of matrix was applied on the

fabric. A layer of carbon fiber was placed on the E-glass layer. Similarly layers of glass fabric and carbon fabric were laid up alternatively and bonded to each other using the matrix to make up the laminate to 11 layers and a thickness of 2.5mm. After the lay-up process the next stage was the vacuum bagging process. A perforated film was laid up on the top surface of the lay-up. The entire system was sealed under a polythene film and suction was created using a vacuum suction pump under a pressure of 500mm of Hg. The laminate was then left for curing at room temperature for 24 hours. The next stage in the curing process was hot air curing. This was carried out in a hot air oven. The rate of heating was 30C per minute. The laminate was maintained at a constant temperature of 800C for 2 hours. After hot air curing, the dried laminate was cooled at room temperature. Specimens of the required orientation were cut from the cured laminate shown (Figure 1). The ASTM standard used for preparing the sample was ASTM D3039/D3039M-00[10S] (Figure 2).



(a) **(b)**

Figure 1 (a) & (b): Fabricated Test Specimens



(a) Without Hole **(b) With Hole**

Figure 2 (a) & (b): Sample Layout According to ASTM D3039/D3039M-00 (All in mm)

Test Setup

The specimens were tested on a computer controlled servo actuated hydraulic universal testing machine. The tests were conducted at room temperature and closely monitored. To measure the strain in the specimens, a 25mm extensometer shown in figure 3 was used. It was mounted at the geometric center point of the gauge length. Tensile load was applied up to failure of the specimens. The cross head speed was maintained at 2mm/min throughout the test.Corresponding to each load, deformation, stress and strain were recorded for each specimen and graphs of stress v/s strain were plotted.

Figure 3: 25mm Extensometer Attached to the Test Specimen Mounted in UTM

RESULTS AND DISCUSSIONS

The failed specimens showed very different failure modes depending on their ply angle. The three primary modes of failure observed in the fracture of angle-ply laminates are fiber separation, fiber breakage and ply delamination. Total failure of a laminate can occur by any combination of these three modes. It was observed that the failure of the hybrid unidirectional composite specimens occurred along the direction of the fiber. The failure of specimens with the hole was observed at the periphery of the hole. However, for the specimen without the hole the failure occurred off center (Figure 4).

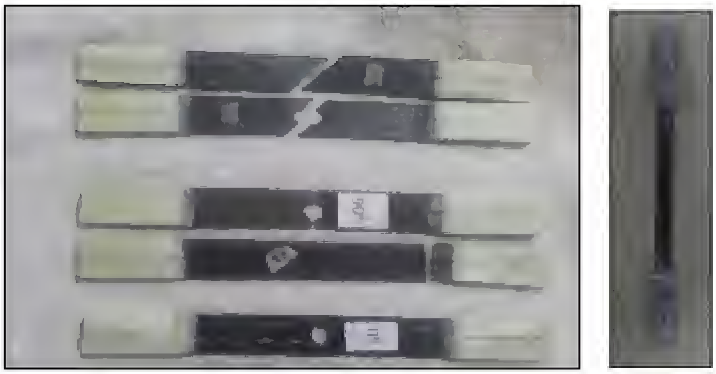
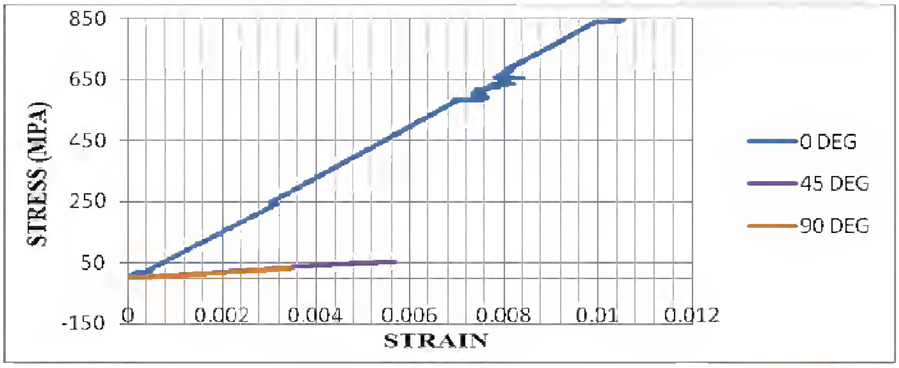


Figure 4: Failure of the Hybrid Unidirectional Composite Specimens Occurred along the Direction of the Fiber

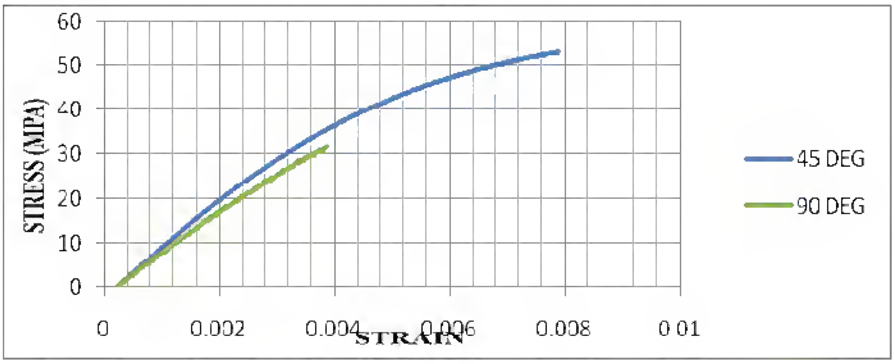
Figures 5 & 6 show the stress strain curves for the samples without and with holes. The results obtained are tabulated in table 1.As seen in the results, the specimens with 0^0 fiber orientations show the maximum tensile strength and those with 90^0 fiber orientations show the minimum tensile strength. This behavior is attributed to the property of the composite materials to exhibit the maximum failure strength in the direction of the fibers. The experimental value of SCF is calculated as a ratio of the peak stress forthe sample without hole to the peak stress for the sample with the hole. This calculation is done for the samples with each orientation considered.

$$SCF = \frac{\sigma_{\max}}{\sigma_{nom}}$$

Stress concentration is induced around the periphery of the central circular hole in the samples with the holes. Since the fibers are discontinuous at the periphery of the hole, the effective load carrying capability of the fibers is significantly reduced and thus causing failure at a lesser load than that required by the sample without the hole. The calculation of SCF from the experimentally obtained data reveal that the SCF is maximum for the samples with 90^0 fiber orientations and minimum for 0^0 fiber orientations.

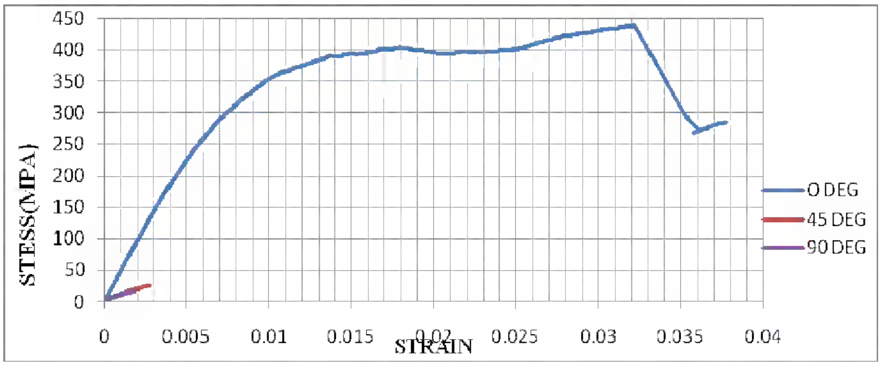


(a)

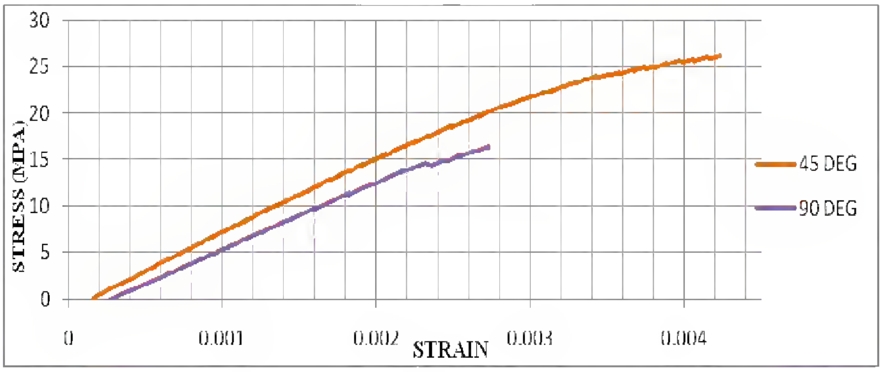


(b)

Figure 5 (a) & (b): Stress v/s Strain Curves for Specimens without Hole



(a)



(b)

Figure 6 (a) & (b): Stress v/s Strain Curves for Specimens with Hole

Table 1: Results of Tensile Test

Fiber Orientation (Degrees to Loading Axis)	Peak Stress for the Specimen without Hole (MPa)	Peak Stress for the Specimen with Hole(MPa)	Stress Concentration Factor
0^0	865.897	439.84	1.95
45^0	51.57	25.96	1.98
90^0	32.24	15.995	2.12

CONCLUSIONS

In this study, the SCF in hybrid unidirectional composites of carbon/E-glass fibers with a central circular hole was evaluated for different orientations of the fibers. The diameter of the hole was 10mm. The orientations considered for the study were 0^0, 45^0 and 90^0. All the layers were oriented in the same direction. It is clear that the fiber orientation has a significant influence on the stress concentration factor in hybrid unidirectional carbon/E-glass composites. The effect of fiber orientation on the SCF was studied. The SCF was found to be least for 0^0 ply orientation and maximum for 90^0 ply orientation. Thus the characterization of SCF for different fiber orientation was carried out.

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